Search for the Flavor-Changing Neutral-Current Decay, $\Sigma^+ \to p\,\mu^+\,\mu^-$

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- Introduction
- Event Selection and background study
- Interpretations of the results
- Summary

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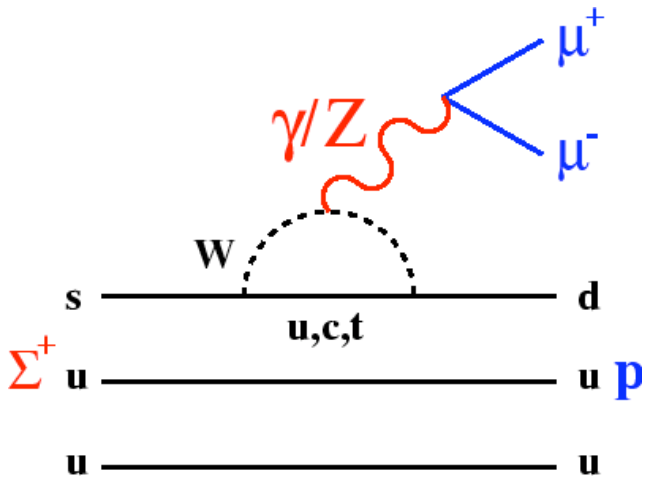
Introduction and Physics Motivation

- No observation of FCNC in the baryon sector

- PDG :
  $B(\Sigma^+ \rightarrow p\, e^+ e^-) < 7 \times 10^{-6}$
  $B(\Lambda_c^+ \rightarrow p\mu^+\mu^-) < 3.4 \times 10^{-4}$

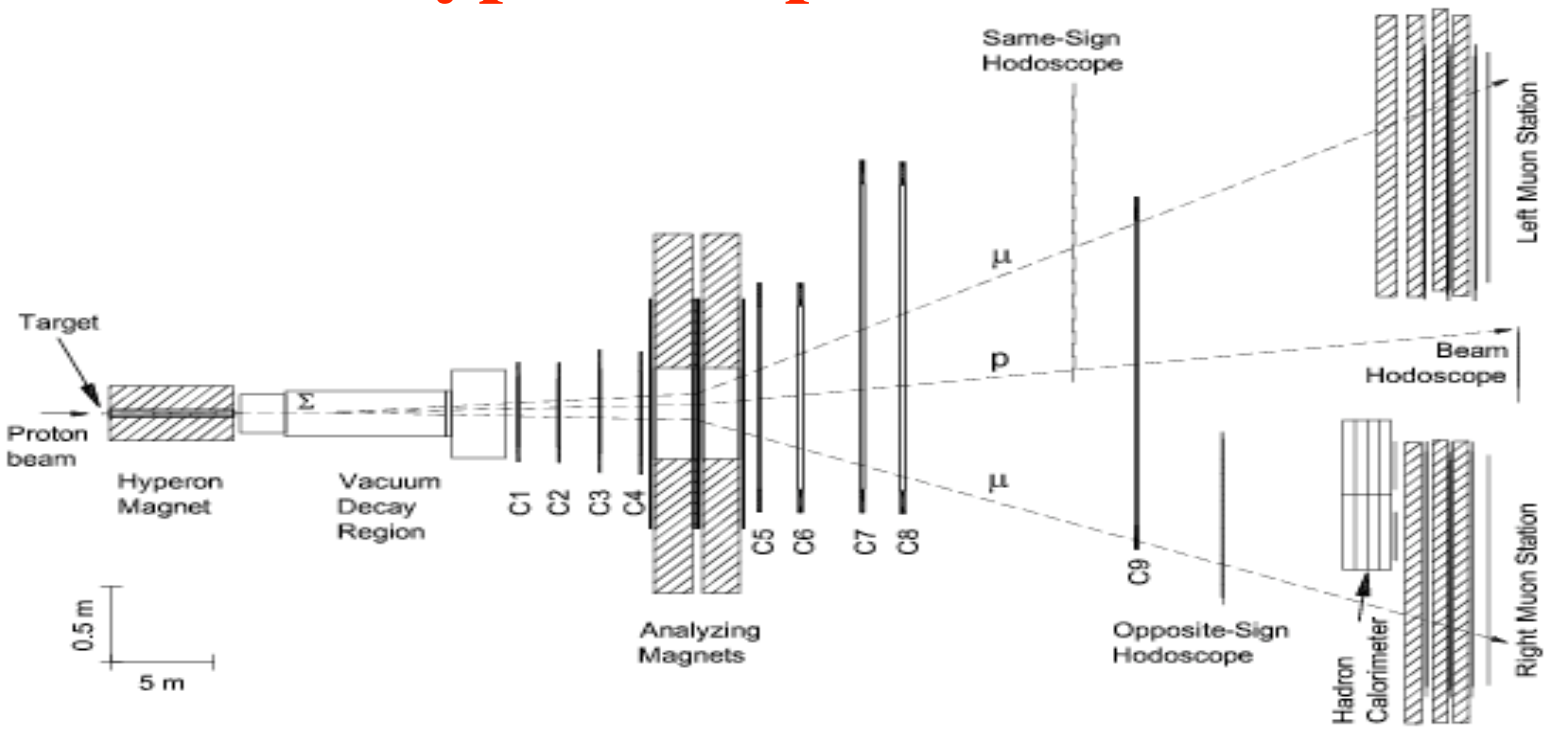


- Theory:

$$\frac{1}{1210} \leq \frac{B(\Sigma^+ \rightarrow p\mu^+\mu^-)}{B(\Sigma^+ \rightarrow pe^+e^-)} \leq \frac{1}{120}$$

(L. Bergström, R. Safadi and P. Singer, Z. Phys. C **37**, 281 (1988))

HyperCP Spectrometer



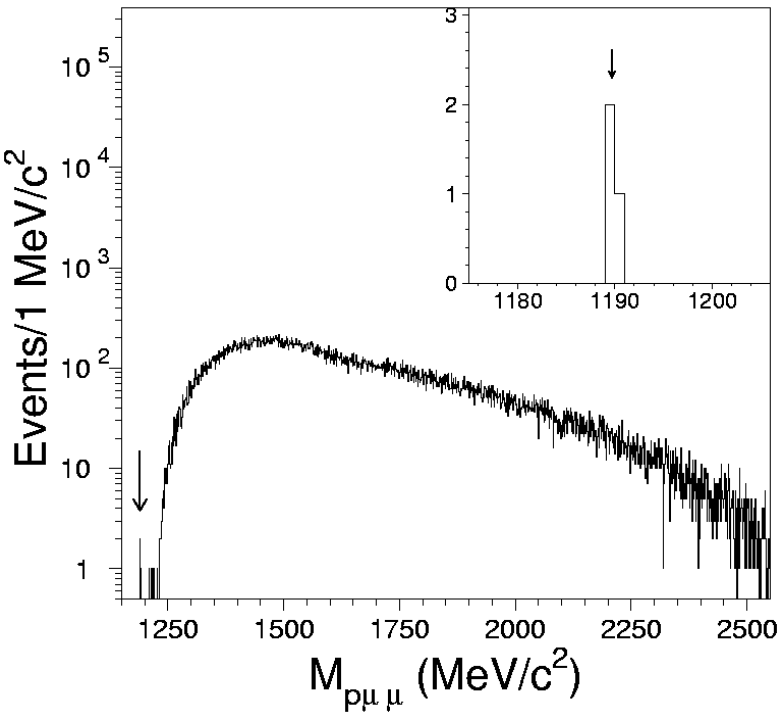
- Two muon stations in left and right side
- Total 3.2 (2.3) m-thick steel absorber in left (right) side
- In each station: 3 layers of proportional tubes
  2 hodoscope planes for trigger
- No. of Σ^+ is more than of Ξ^- ($\sim 10^9$) in HyperCP data

Event Selection for $\Sigma^+ \rightarrow p\mu^+\mu^-$

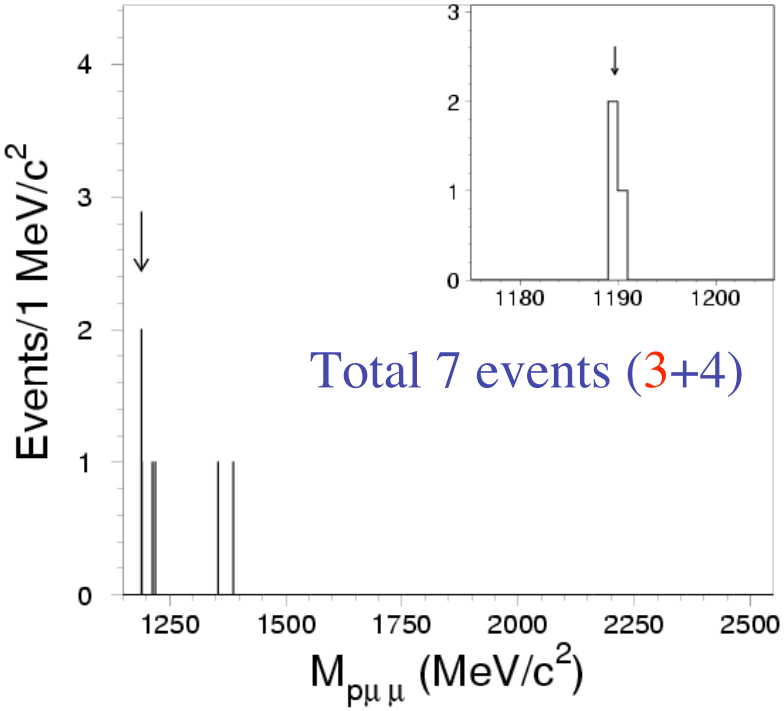
- Use full data set, positive and negative data for '97 and '99 runs
  Split two exclusive samples:
  single muon and dimuon samples
- Basic Selection Cuts:
  3 tracks: μ^+,μ^-, proton
  Decay vertex within the vacuum decay pipe
  Good single vertex
  Event from the target
  120 GeV < P_{tot} < 240 GeV
- Proton momentum fraction, $f_{had} > 0.68$
- Reconstruct mass under $\Sigma^+ \rightarrow p\mu^+\mu^-$ decay hypothesis

Event Selection for $\Sigma^+ \rightarrow p\mu^+\mu^-$ (con't)

Basic selection cut



Basic selection and f_{had} cuts



- Observed 3 candidates within 1 σ of mass resolution (1 MeV/c^2): only in '99 positive dimuon data
- Backgrounds were more than 20 σ from Σ^+ mass.

Background Study: K^+ decays (I)

- 1.0 x 10^{10} K^+ decays in '99 positive data
- Backgrounds from K^+ decays:

  $K^+ \rightarrow \pi^+\pi^+\pi^-$, $K^+ \rightarrow \pi^+\pi^-\mu^+\nu$

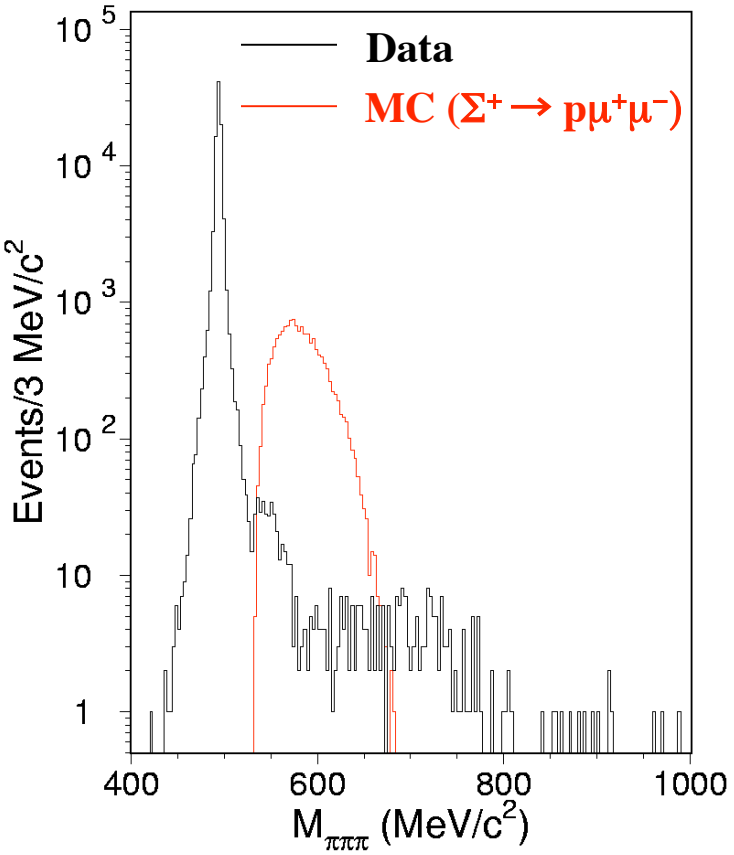
  $K^+ \rightarrow \pi^+\mu^+\mu^-$, $K^+ \rightarrow \mu^+\mu^-\mu^+\nu$

- In MC study, none of them are serious sources:

  Used 40 to 100 times more MC events than the number of expected backgrounds

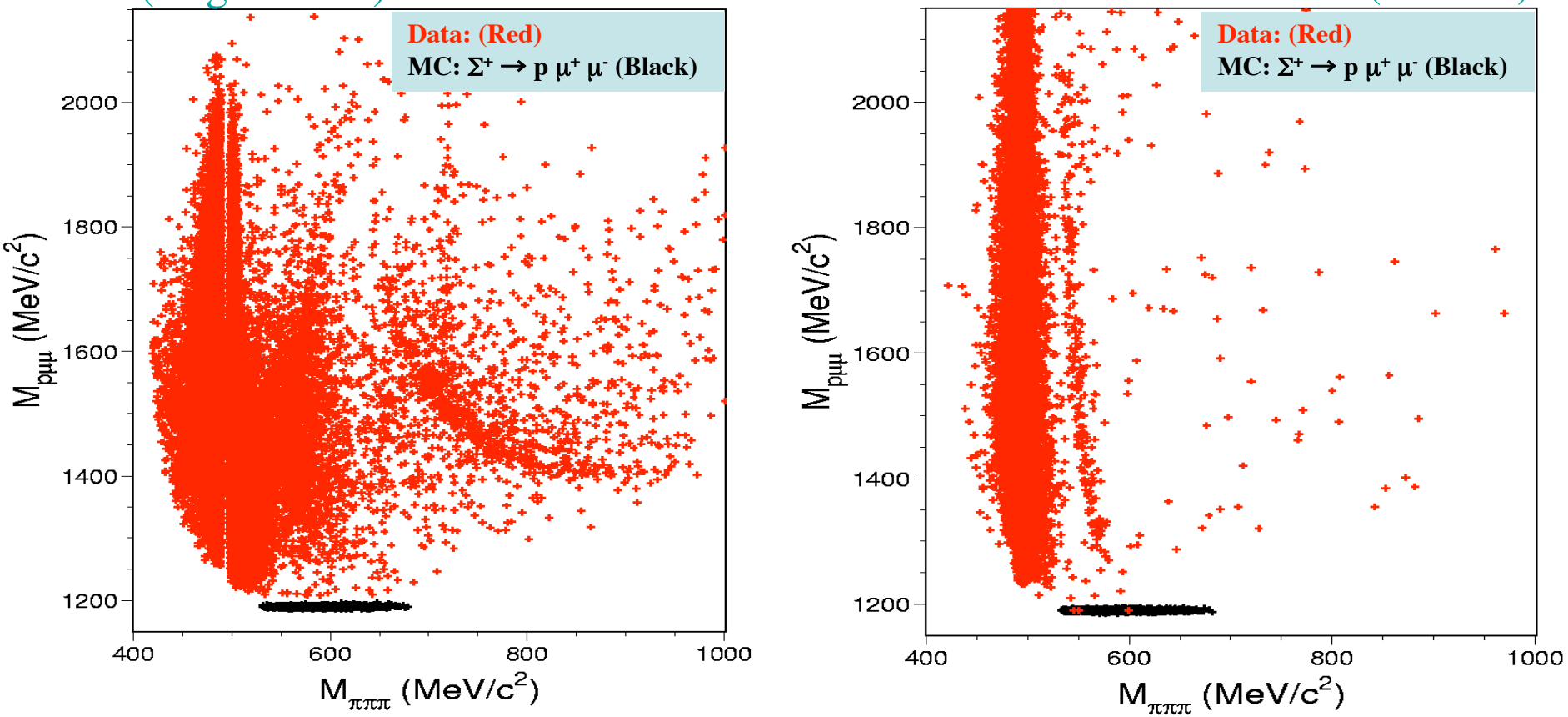
- Non-gaussian tails of K^+ decays

  Need to check with real data



Background Study: K^+ decays (II)

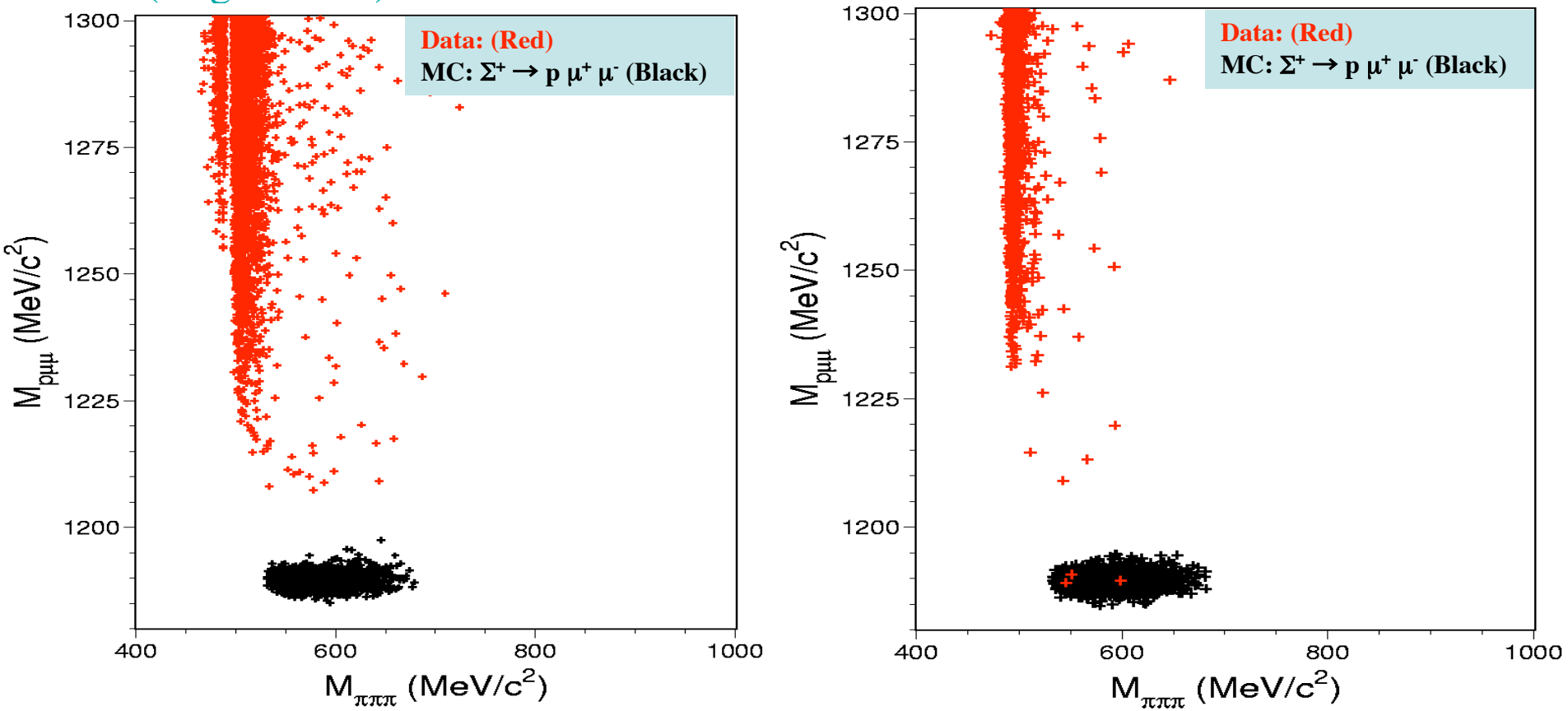
(single muon) Basic Selection Cut (dimuon)



- Use the single-muon sample: 30 times larger than the dimuon sample
  (The acceptance in the single-muon sample is lower)
- In the single-muon sample:
  more background, no events below 1200 MeV/c^2

Background Study: K^+ decays (II)

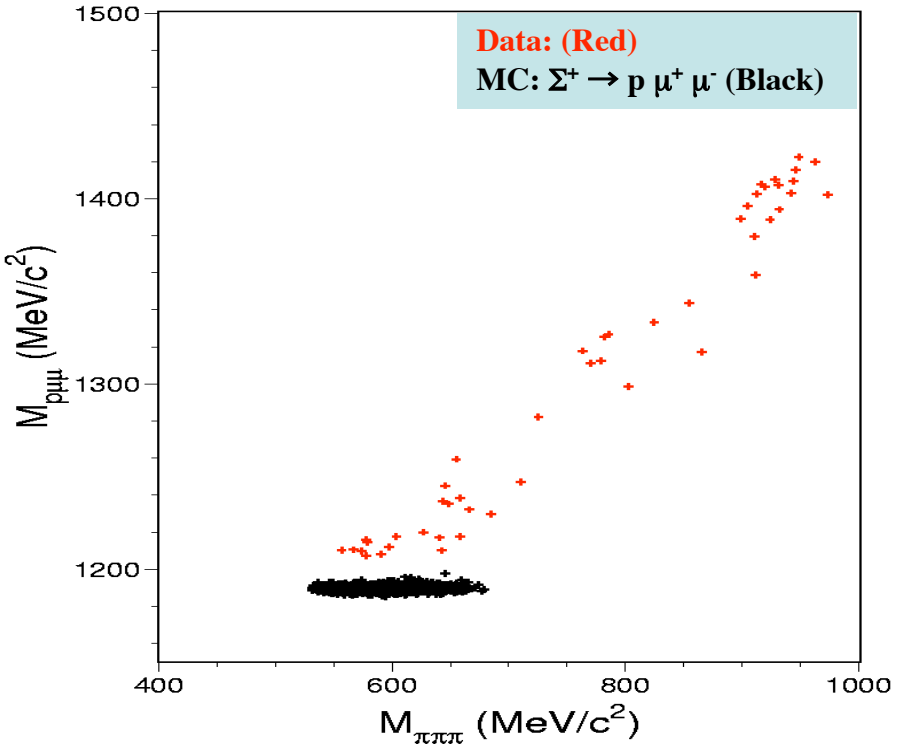
(single muon) Basic Selection Cut (dimuon)

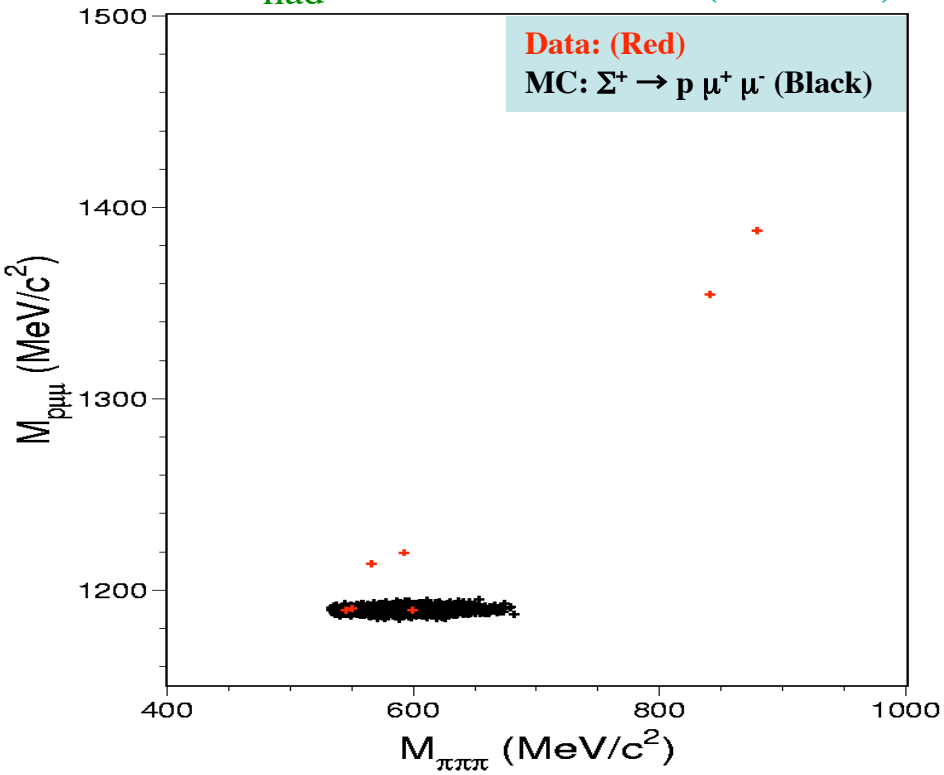


- Use the single-muon sample: 30 times larger than the dimuon sample
  (The acceptance in the single-muon sample is lower)
- In the single-muon sample:
  more background, no events below 1200 MeV/c^2

Background Study: K^+ decays (III)

(single muon) Basic Selection and f_{had} Cuts (dimuon)





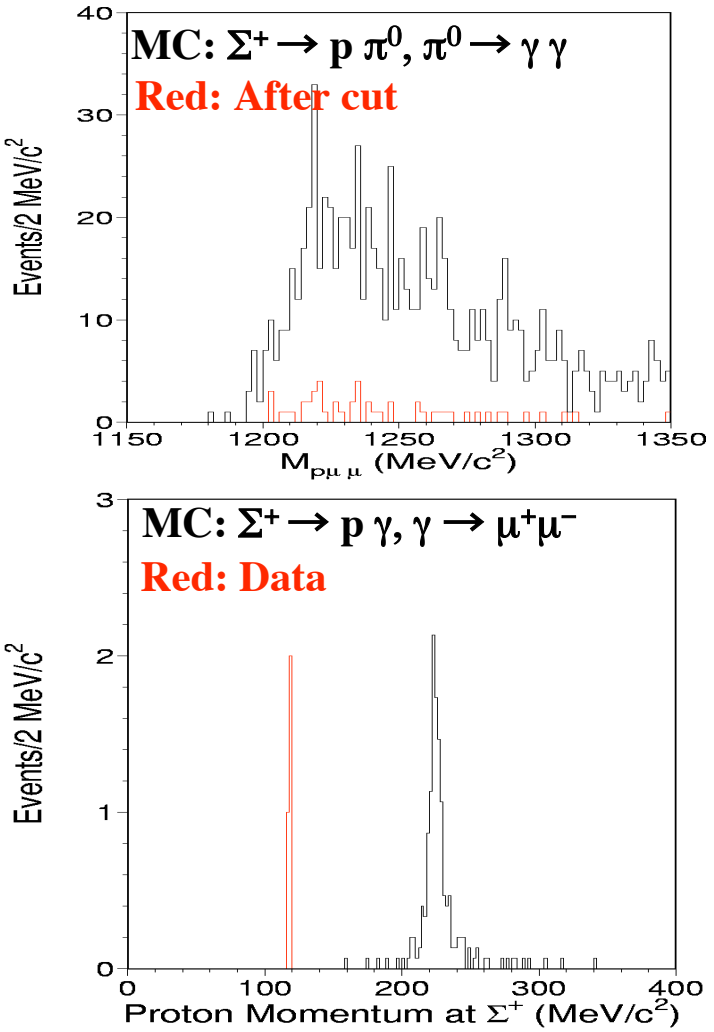
- Almost no K^+ decays in both samples.
- Background level above 1200 MeV/ c^2 in the dimuon sample:
  (3.6 ± 0.5) events estimated from the single muon sample
  4 events observed in the dimuon sample

Background Study: Photon Conversion (IV)

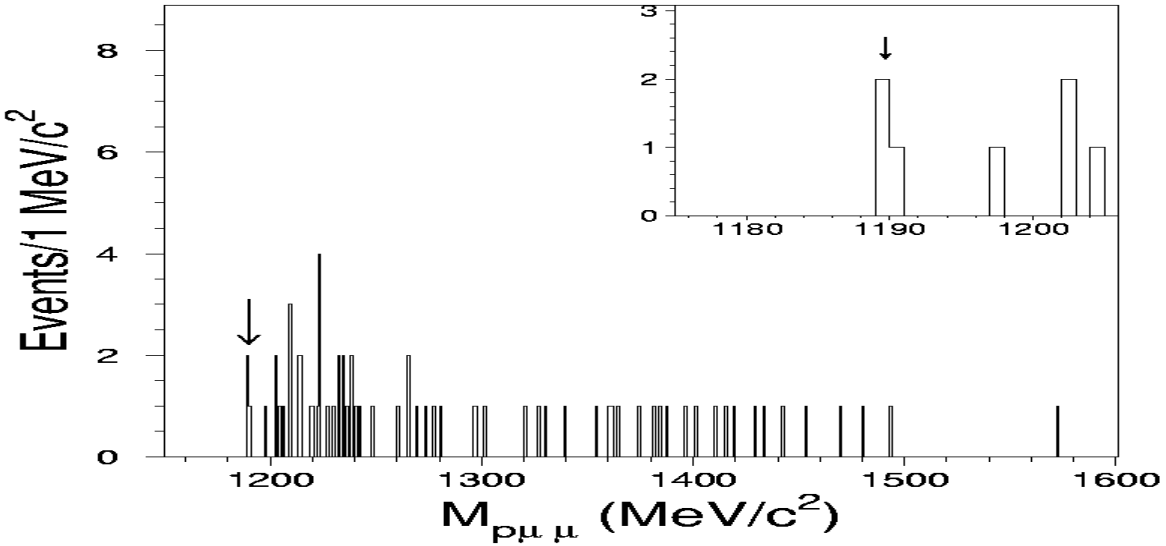
- The probability for γ **conversion to $\mu^+\mu^-$** at the window of the decay pipe: ~10^{-7}
- Photon sources from known decays:
  $K^+ \rightarrow \pi^+ \pi^0$, $K^+ \rightarrow \pi^+ \gamma \gamma$
  $\Sigma^+ \rightarrow p \pi^0$, $\Sigma^+ \rightarrow p \gamma$

- Dimuon Trigger acceptance: ~10^{-4}
- Used 100~1000 times more MC events than the expected background level

- Checked proton momentum at the rest frame of Σ^+ **for 3 candidate events**
- Should see some in the single-muon samples



Background Study: Dimuon Sample (V)

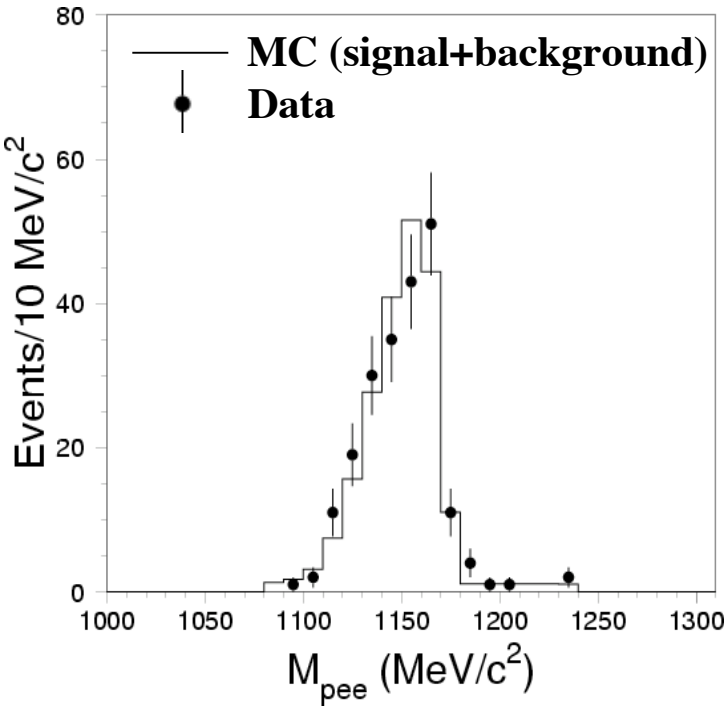


- Relaxed the cut values for the dimuon sample:
  Increased background level but still no events within 8 σ
- No signal events in '99 neg. and '97 pos./neg. dimuon sample:
  $\bar{\Sigma}^-$ production is suppressed by ~10 for negative data
  The dimuon sample for '97 pos. data is 3 times smaller than for '99 pos. data.

Based on background studies, the candidates are unlikely due to background.

Normalization of $\Sigma^+ \rightarrow p\mu^+\mu^-$ Branching Ratio

- Use prescaled (=100) data
- Select $\Sigma^+ \rightarrow p\,\pi^0$, $\pi^0 \rightarrow e^+ e^- \gamma$ decays as the normalization event
- Trigger Acceptance: 2.6 x 10^{-3}
  Event selection efficiency: 5.6%
- Compared M_{pee} distribution for the data with MC signal and background events:
  N_{norm}=(189.7 ± 27.4)
- No. of Σ^+ decays in '99 positive data:
  (2.14 ±0.31) x 10^{10}

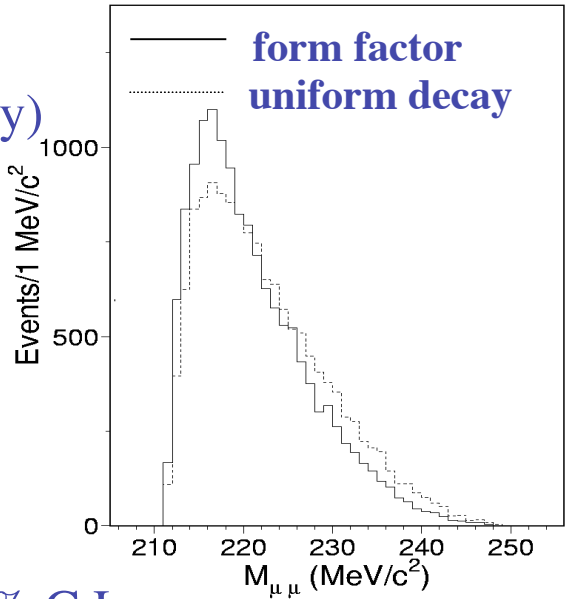


Interpretations of Results: $\Sigma^+ \rightarrow p\mu^+\mu^-$

- If 3 candidates are $\Sigma^+ \rightarrow p\mu^+\mu^-$ decays,

$$B(\Sigma^+ \rightarrow p\mu^+\mu^-) = [1.3^{+1.0}_{-0.8} \pm 0.7]\times10^{-7} \text{ (uniform decay)}$$

$$B(\Sigma^+ \rightarrow p\mu^+\mu^-) = [8.6^{+6.6}_{-5.4} \pm 5.0]\times10^{-8} \text{ (form factor)}$$



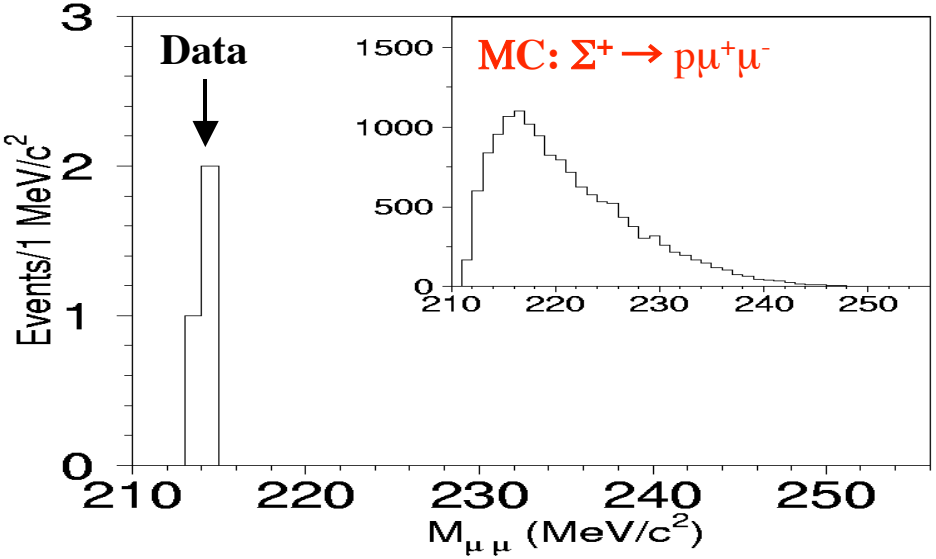
- If they are background,

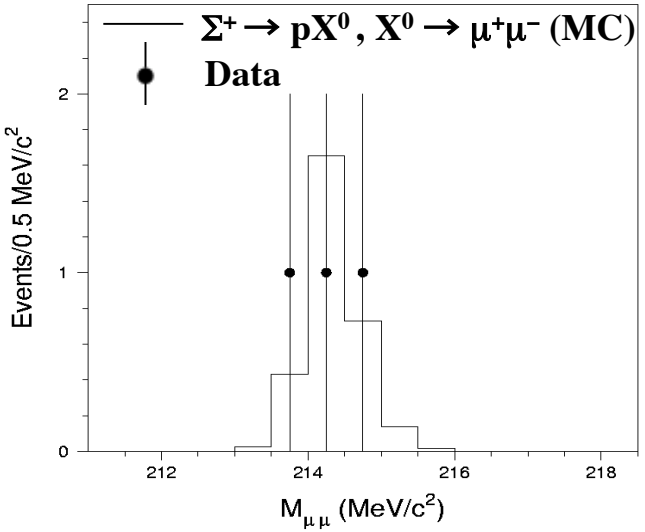
$$B(\Sigma^+ \rightarrow p\mu^+\mu^-) < 1.6\times10^{-7} \text{ (uniform decay), @ 90\% C.L.}$$

$$B(\Sigma^+ \rightarrow p\mu^+\mu^-) < 1.1\times10^{-7} \text{ (form factor), @ 90\% C.L.}$$

Interpretations of Results: $\Sigma^+ \to pX^0$, $X^0 \to \mu^+\mu^-$

- Dimuon masses for 3 candidates are clustered within ~ 1 MeV/c^2.





- Probability for dimuon masses of 3 events to be within 1 MeV for $\Sigma^+ \to p\mu^+\mu^-$ decays is less than 1%.
- Suggests two-body decays, **$\Sigma^+ \to pX^0$, $X^0 \to \mu^+\mu^-$:**

$$M_{X^0} = (214.3 \pm 0.5)\,\mathrm{MeV/c^2}$$

$$B(\Sigma^+ \to pX^0, X^0 \to \mu^+\mu^-) = [3.1^{+2.4}_{-1.9} \pm 1.5] \times 10^{-8}$$

Systematics for Each Scenario

	$\Sigma^+ \to p\mu^+\mu^-$	$\Sigma^+ \to pX^0, X^0 \to \mu^+\mu^-$
	uniform decay (form factor)	
Source	σ_B/B (%)	σ_B/B (%)
Normalization	14.7 (14.7)	14.7
Modeling of Σ^+ production	52.1 (54.3)	44.6
Beam targeting	11.5 (11.1)	8.7
Magnetic field	3.8 (2.2)	3.9
Trigger efficiency	1.5 (1.5)	1.5
Muon identification	0.3 (0.3)	0.3
$\Sigma^+_{p\mu\mu}$ decay model	(8.8)	
π^0 form factor	1.8 (1.8)	1.8
$B(\Sigma^+ \to p\pi^0)$	0.6 (0.6)	0.6
$B(\pi^0 \to ee\gamma)$	2.7 (2.7)	2.7
MC statistics	1.3 (1.3)	1.3
Total	55.6 (58.2)	48.1

- Main source of systematic error: modeling of Σ^+ momentum spectrum
- Total systematic error is comparable to the statistical error.

Summary
(HyperCP Preliminary)

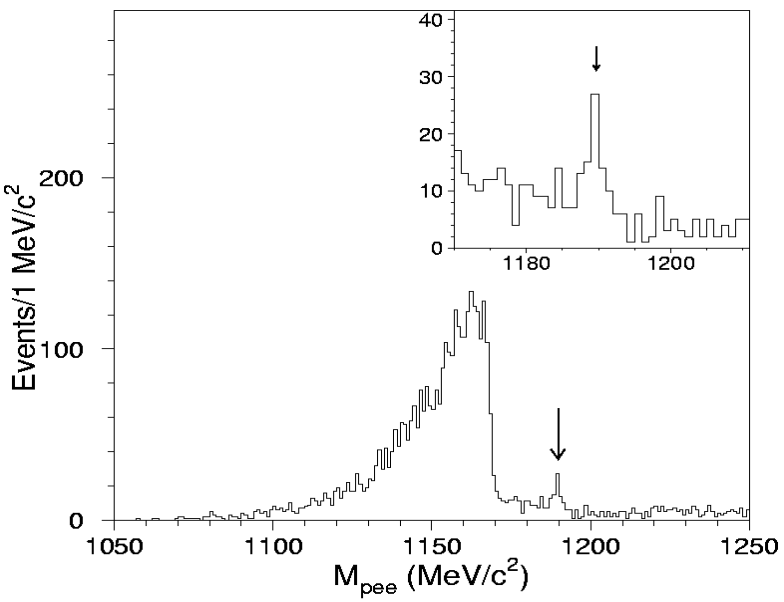
- We observed three candidates with p μ^+ μ^- mass consistent with Σ^+ decays: No background within 20 σ
- If they are genuine $\Sigma^+ \rightarrow p\mu^+\mu^-$ decays, first observation of FCNC in the baryon sector.

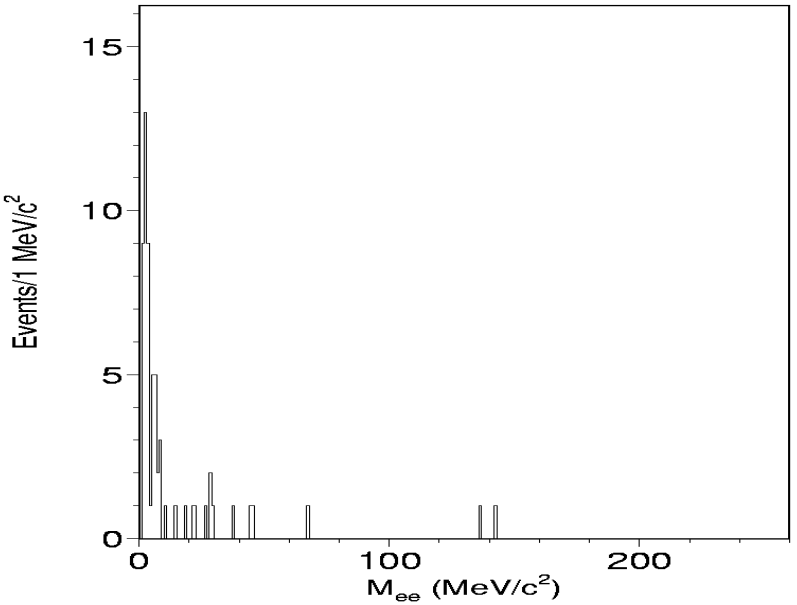
  $B(\Sigma^+ \rightarrow p\mu^+\mu^-) = [8.6^{+6.6}_{-5.4} \pm 5.0] \times 10^{-8}$ (form factor)
- The dimuon masses for three candidates are clustered within ~ 1 MeV/c^2, which could imply

  $\Sigma^+ \rightarrow pX^0$, $X^0 \rightarrow \mu^+\mu^-$, $M_{X^0} = (214.3 \pm 0.5)$ MeV/c^2
- Further work is needed to confirm our result.

Backup Slides

Search for $\Sigma^+ \rightarrow p\, e^+ e^-$ Decays





- Observed the peak at Σ^+ with the hypothesis, $\Sigma^+ \rightarrow p\, e^+ e^-$ decays
- In very preliminary study with a small data set and MC study of $\Sigma^+ \rightarrow p\, \gamma$, $\gamma \rightarrow e^+ e^-$, the observed peak seems to be consistent with $\Sigma^+ \rightarrow p\, e^+ e^-$ decays.